Electrical Machines - I
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Lecture - 01
Magnetic Circuit and Transformer

Welcome to this course on Electrical Machines – I, where we will discuss about Transformers and DC machines. These are the two major topics. And we will begin with transformers.

Transformers as we will see will generally consist of a magnetic core material made of subtitle, over which there will be at least two coils wound. And one of the coil will be energized with AC source of known frequency and in the other coil will get voltage of same frequency, but at different levels. So, that is primarily the job of a transformer is, that is suppose you have a 200 volt 50 Hertz supply, you require 400 volt 50 Hertz supply, then I will use a transformer to change the level of the voltage from 200 to 400 volt keeping the frequency constant.

It can be similarly a step down situation where you have a say 400 volt you want to step it down to 100 volt level then use a transformer. Transformer is a static device its efficiency is very large. In case of power transformer efficiency could be as large as 99 percent unlike a rotating machine efficiency which may be 80 percent, 85 percent very good efficiency because there is no rotating parts in it.

There will be of course, losses which accounts for that 1 percent or 2 percent loss in power, that is there because of conductors will carry current it will have a high square or loss. And also core we will see when it is having a time varying flux then also there will be heat loss inside the core of the material. Anyway, those things we will discuss in detail.

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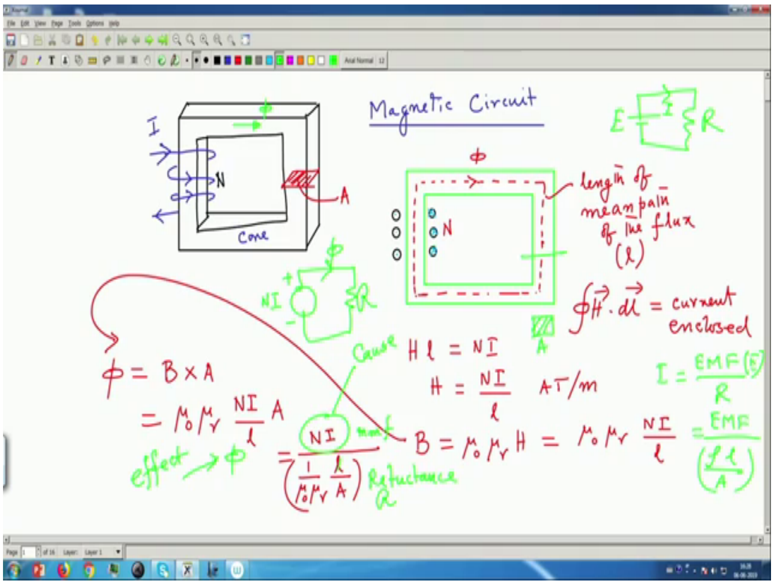

But it looks like then we have to deal with this situations, that is suppose you have a magnetic core of this kind ok. And it has got a thickness, like this in 3 dimension I am trying to draw and it will be like this. So, this is called it is a made of soft iron and I have drawn it right now as a solid iron block. We will see what is to be done because solid irons are not used.

But this is the structure of the iron and over which there will be coils wound like this ok. When there is a single coil and there is a core like this, core material then if this coil carries current it will produce flux inside the core. So, we start with magnetic circuit ok. We just review that because that will be essential in understanding the.

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Magnetic circuit because there is a magnetic material, there will be coils wound over it and the coils are supposed to carry current therefore, they are going to produce flux in the core. And we know that if this is the direction of the current, suppose DC current first then the direction of the current will be like this in the coil, I. Suppose we have connected DC source this is the current. Then what happens, in the core there will be a flux produced phi. Deduction of the flux will be as you know you wrap your fingers around the coils and thumb will give you the direction of the flux produced.

Of course, if it is a constant DC current whatever flux will be produced inside the core that too will have constant values; and how to estimate that flux? You know we apply the ampere circuital law to find out the flux produced in the core. For example, you see if I draw the sectional view of the core, like this, then if you draw the sectional view the conductors can be shown to be like this, this is the coil sections. How many coils sections you will see? As is the number of turns of this one. And the direction of the current as shown can be shown by cross and dot like this will be cross current, [FL] cross and these will be dot, is it not?

Then the flux inside the core what do we do is we take a mean path of the flux which I am showing by dotted lines. This is the flux and this red one is the length of the mean path, length of mean path of the flux that length let me call l. If these are N then ampere circuital laws says that integral H dot dl over a closed path is equal to current enclosed, is it. But in this case the direction of H and l are same.

Therefore, what will come out to be H into l that dot product because the direction of H and l as I move they are same, direction of H, direction of B, direction of phi they are all same and also length is like that, H dot dl means H into l should be equal to the current enclosed. How much current is enclosed by this path? N into I, N into I. We know this, so I will not spend much of this time.

So, this is NI by l. Its unit is ampere turns per meter this will be the case. Once I know H then I will calculate B, B will be equal to mu 0 mu r into H, where mu are is called the relative permeability of the core and if the relationship between B and H is linear, then mu r is a constant value and so this will be equal to mu 0 mu r and for H I can write NI by l. Then the then I go here, then the flux produced which is in vapor will be equal to B into the cross sectional area A. What is this A? A is this cross sectional area that is this, this, this, this, through which flux will be flowing, so, this is A ok.

So, this cross sectional area is perpendicular to the flux at any sections therefore, flux in vapor will be B into A and B already I have calculated, so I substitute that mu 0 mu r NI by l, this is H into area. Now, if you see this can be written as NI I am sorry, if you see this it will be NI and bring all the other things in the denominator which will become 1 by mu 0 mu r l by A. Why I have written in this fashion is this, that this is the cause I can identify this, this is the cause and phi is the effect, is not? I have supplied with mmf and this magnetic circuit returns c way flux phi. And how to calculate that flux? Mmf, this is called mmf and you this is called reluctance. And that is why we name magnetic circuit.

In case of electrical circuit, I is equal to EMF by resistance and if you recall EMF is EMF voltage resistance is rho l by A. So, there is a striking similarity and that is why it is called reluctance. Reluctance limits the value of the flux when you apply an mmf. Although, the mmf and the flux in electrical circuit as you know the circuit is like this resistance and this is your EMF say E E by R. And this is the current, but in magnetic circuit this mmf and this flux wherever it is flowing they are totally decoupled, I mean it is not that flux is in the conductor.

But nonetheless this equation prompts us to simplify the matter and say that as so far as calculation of mmf is concerned you do it like this NI and connect it by a reluctance which is shown by a curly letter R and here you show the flux. Although, in this diagram I show there as if connected, but they are not in practice, but only prompted by this relationship corresponding in the existing in the electrical circuit, it is better, that is why it is called magnetic circuit.

So, if mmf is known. I will first calculate, what is the reluctance? Reluctance of the magnetic circuit per depends upon its geometry, what is the length, what is the cross sectional area, cross sectional area is this one of this, this is the cross sectional area then you calculate H and I by l and then multiply it with mu 0 mu r to get B, then multiply with a and get that one. Therefore, in a simple excitation with DC current this value of the flux whatever you will get, if you divide the mmf with reluctance that two will be constant and its direction will be also fixed in this case it is clockwise ok.

The reverse problem is also very simple. In that case I will say that I want to create a certain amount of flux what should be the current necessary. So, I will calculate reluctance, reluctance into flux will give me NI and if I know the number of turns I will simply divide that NI with m to get the current necessary. Anyway, these are known stuff and we have a magnetic circuit like this ok. And I will presume that you know about it, so no question of further telling about it [FL]. Now, we will go to next page, next page.

Student: L that keyboard is (Refer Time: 16:21) useful.

Let us go to next page.

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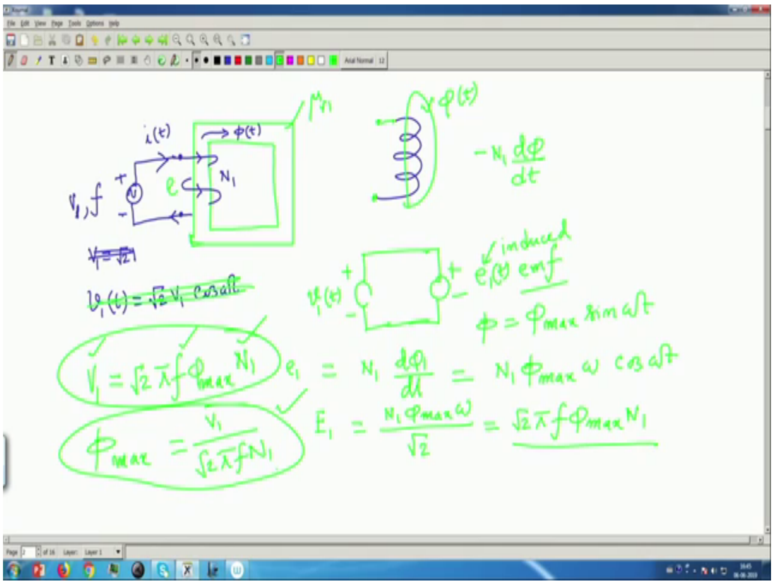

Now, I will tell you that what happens if the same magnetic circuit that is this one, this point you listen very carefully and this is the most interesting thing, sorry, I am sorry. Let me try to draw another thing here, that is the core I am drawing you must understand. Why it is getting circle, anyway.

So, suppose this is the core of the material let me draw slowly ok. And suppose you have the let us consider a single coil same magnetic circuit with N turns, but this time what I will do is this I will connect it to an AC source this is AC source of known voltage.

For example, V 1 is equal to root 2 I am sorry will write it like this v 1 t is equal to root 2 V 1, some say sin omega t or cos omega t I will write it applied voltage to this coil. Now, if you pass a sinusoidal voltage across the coil, in case of DC circuit magnetic circuit what I was telling when the current is constant then NI you calculate mmf divide it by reluctance get the flux. But in AC circuit AC magnetic circuit the coil is connected across a AC supply voltage of known frequency, rms value V 1 and supply frequency is f.

Then what I am telling, first I will tell this statement the flux in the core gets fixed I mean no question of once the supply voltage and rms value is known, I mean we do not start telling that I will first calculate current, then calculate mmf, then divide that mmf with reluctance to get the flux, not like that; it will be the moment you apply a known rms voltage at certain frequency f where omega equal to 2 phi f and AC voltage across the coil.

The level of flux which will be produced which will be also time varying it is expected flux gets fixed. Now, what is the reason for that? Reason for that is it is expected whatever current it draws that will be also sinusoidal varying, because after all it is some sort of coil or inductance we have connected across an AC supply, some alternating current it will draw and since current value and magnitude is changing with time the this phi 2 will be time dependent, sometimes it will be flowing to clockwise sometimes in the anticlockwise direction, sometimes it will be 0 when the instantaneous value of the current will be 0 and so on. But the moment an alternating flux is created inside the core of the coil, inside the core of this magnetic circuit between these two points they are appears an AC induced voltage.

Suppose the number of turns of this coil is N or say N 1 single coil l 1. Then according to Faraday if there is a coil if there is a time varying flux in the coil then this coil itself become a seat of EMF. The value of instantaneous value of which is some minus N 1 d phi d t about that sign it is not necessarily so important, but what I am telling this is the induced voltage the flux linking the coil is chaining with time and therefore, there will be induced voltage across this coil.

In this case this flux is created by the current carried by the coil itself, but it does not matter, Faraday says, if there is a change of flux rate of change of flux exists linking a coil it is time bearing then between these two points it will become a seat of EMF. Negative sign is the Langer's law it tells that the polarity of this induced voltage will be such that it will try to oppose the very cause for which it is due.

For example, this coil can be modeled as here is your AC supply V 1 t I have applied. Then what I am telling across this coil if I neglect the resistance of the coil there appears another source here and that induced voltage is E 1 and the polarity of this voltage will be such that if this side is d phi dt is positive then it will try to oppose the cause, so its polarity will be like this ok. Or in other words what I am telling, so these thing can be now be modeled like these applied voltage and there is another induced EMF.

In case of DC magnetic circuit DC 1 will not be there, there is applied voltage which is constant. Of course, current will be limited by the resistance of the circuit V by r that is why current gets fixed I. But here what I am telling the induced voltage in the coil will be same as the applied voltage, only thing about the polarity its polarity will be such that it will try to oppose the cause very cause that is the flux it will try to oppose it. What was the reason for flux existing and increasing? This current it was increasing in the positive direction. So, it will try to limit reduce that value of the current that was the reason.

Anyway, after this I can say that in this loop k V l equation is to be satisfied. Therefore, applied rms voltage must be equal to the rms voltage of V 1 what else, is not? Now, you see this flux will be some phi max, say let us forget about this cos omega d sin suppose I start with these one phi max equal to sin omega t. Why I am assuming this? Because the circuit cannot, but draw sinusoidally varying current let call phi is equal to phi max sin omega t. If that be the case then the rms value of the then the induced voltage in the coil E 1 will be equal to N 1 d phi 1 dt ok.

If you differentiate these this will become equal to N 1 phi max omega sum cos omega t. This will the value of the induced voltage, is not? So, what will be the rms value of that voltage? It will be the peak value of the voltage phi max, omega by root 2. For omega if you substitute 2 phi f, so it will become root 2 phi f phi max into N 1. See I am not so much bothered about this minus 1, I should not struggle, my intention here is to calculate what is the rms value of the induced voltage ok. Differentiate it, peak value you get divide it by root 2 and that will give you rms voltage.

What I am telling is in the circuit k V l equation must be satisfied or is vanishingly small. So, applied rms voltage must be equal to the induced rms voltage it cannot be other than that. Therefore, if the applied rms voltage is V 1 it must be equal to root 2 phi f phi max into N 1 is it has to be f nothing other than that.

So, what I have told you that in case of AC E same magnetic circuit which I considered with DC excitation, if you connect it to an external voltage source which is alternating in nature sinusoidally and the rms value of that applied voltage is known current whatever flows has to be sinusoidal therefore, phi created inside the core of this magnetic material 2 will be time dependent and vary sinusoidally. And if this flux vary sinusoidally then Faraday tells us that across this two points; this two points there will be induced voltage.

What is the magnitude of this induced voltage rms value? That magnitude of this rms voltage is root 2 phi f phi max into N 1. Applied rms voltage is known V 1, induced rms voltage is known capital E 1 and these two must be same because k V l is to be satisfied in the primary. If that be the case in this equation what are the things I know, V 1 is known, supply frequency is known, N 1 is known number of turns and your phi max is equal to V 1 by root 2 phi f into N 1. This is the crucial thing.

As I told you see mind you in case of alternating magnetic circuit if you apply an AC voltage the level of flux phi max is decided, decided by whom? By the supply voltage rms value by the supply frequency and number of turns; so, is it not? Something different from DC circuit; DC circuit you apply some known current, DC current in the circuit calculate mmf divide by reluctance, get the flux. But here it is somewhat interesting.

The moment you connect an AC voltage V 1 and f I can tell you the flux is sinusoidally varying. What is the maximum value of that flux? It is fixed it is this one. Therefore, this phi max how much will be produced inside the core is decided. I do not have any control over it. In fact, I will go a step ahead I will tell you. If this core material it has got a permeability of mu r 1 you replace this core material with another magnetic material having relative permeability mu r 2 then also phi max is V 1 by these one.

So, no matter what is the kind of magnetic material it is good magnetic material, back bad magnetic material, the moment supply rms voltage and supply frequency are known phi max in the core is decided. A very crucial point to go ahead with the concept of transformer. We will continue with that.

Thank you.